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ANALYSIS OF STRAIN AND DEFLECTION IN CONCRETE WITH ZEOLITE AS CEMENT SUBSTITUTION USING DIC METHOD

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ABSTRACT

Concrete is one of the most chosen materials in the construction world due to its exceptional properties, such as high compressive strength, fire resistance, and weather resistance. One natural material that can be used as an additive or substitute in concrete to improve, maintain, or even enhance the existing strength of concrete mixtures is zeolite. Adding zeolite to the mixture is expected to minimize strain and deflection compared to the normal concrete. The examination of the mechanical properties of concrete material is crucial to ensure that the material can be used. Several existing concrete material testing methods and equipments require relatively high investment costs. The application of the Digital Image Correlation (DIC) method offers a comprehensive alternative that can replace the expensive traditional strain gauge. This method uses a digital camera and Zeiss Inspect Correlate software. This study aims to determine the effect of zeolite application in concrete as a cement substitute on concrete strain and deflection implementing the DIC method. The results showed that concrete with zeolite substitution has a compressive strength of 25.02 MPa and a flexural strength of 4.13 MPa, which are lower than the compressive and flexural strengths of concrete without zeolite substitution, which are 29.10 MPa and 6.88 MPa, respectively. Additionally, the strain and deflection values obtained from concrete with zeolite substitution are 0.0042 and 1.690 mm, respectively, which are higher than the strain and deflection of concrete without substitution, which are 0.0033 and 1.253 mm, respectively. Therefore, it can be concluded that the addition of zeolite as a cement substitute cannot minimize strain and deflection in concrete and the results of the analysis using the DIC method show a high level of accuracy, proven to be significantly correlated with the measurement results of the instruments.

Keywords : Digital Image Correlation; Zeiss Inspect Correlate; Zeolite; Strain; Deflection.

1. INTRODUCTION

Concrete is one of the most chosen materials in the construction world due to its remarkable ability to withstand high compressive strength, resistance to fire, and resistance to harsh weather [1]. Along with technological advancements in concrete mix production, many additives or substitutes are used in the concrete-making process. This aims to improve, maintain, or even enhance the existing strength of the concrete. One additive used to improve concrete performance is zeolite. Zeolite is a natural material formed from the hydration of alkaline substances with an open network structure that can absorb and release water as well as facilitating ion exchange with its environment [2]. Adding zeolite minerals to the concrete mixture is expected to increase concrete strength and reduce cracks due to deformation. Additionally, the inclusion of zeolite is anticipated to improve the strain and deflection performance of concrete compared to normal concrete. Inspecting the mechanical properties of concrete is essential to ensure its suitability as a construction material. Many inspection methods and equipment currently in use require relatively high investment costs. The application of digital image correlation (DIC) methods offers a comprehensive alternative that can replace expensive traditional strain gauges [3]. The DIC technique, developed over the last few decades, utilizes digital cameras and Zeiss Inspect Correlate software to analyze image correlation. This method can correlate digital images of undeformed and deformed objects to determine the displacements and strains in the observed field [4]. This research aims to obtain empirical data on the performance of the DIC method in examining strain and deflection in concrete, as well as assessing the strain and deflection performance of the concrete with zeolite as a cement substitute. Based on these objectives, this research addresses the topic of "ANALYSIS OF STRAIN AND

DEFLECTION IN CONCRETE WITH ZEOLITE AS CEMENT SUBSTITUTION USING DIC METHOD."

LITERATURE REVIEW

Here are some literature reviews for this research:

A. Strain

Strain is the ratio of the increase in length (ΔL) to the initial length. Strain is written as ε and has no units. The following is the formula used to calculate strain:

$$\varepsilon = \frac{\Delta L}{L} \quad (1)$$

Note:

ε = Concrete strain

ΔL = Change in Length

L = Initial length

Apart from using the formula above, strain can also be obtained if the elastic modulus and yield stress of the material are known, here is the calculation formula:

$$\varepsilon = \frac{\sigma}{E} \quad (2)$$

Note:

E = Modulus elasticity (MPa)

σ = Stress (MPa)

B. Deflection

Deflection is the change in the shape of a beam in the y-direction due to vertical loading of the beam. Based on Ria Yulianti [5] by using two-point loads, to obtain the maximum deflection value, the following formula is used:

$$\delta = \frac{P.a}{24\,EI}\,(3l^2 - 4a^2) \quad (3)$$

$$I = \frac{1}{12}\,(b\ x\ h^3) \quad (4)$$

Note:

δ= Maximum deflection (mm)

P= Compressive force (N)

a= Distance from the support to the loading point (mm)

E= Modulus elasticity (MPa)

l = Length of beam (mm)

I = Moment inertia (cm^4)

C. Zeolite

Based on [6] zeolite is a special mineral that has a unique crystal structure because it is easy to adjust, so the properties of this zeolite can be modified according to needs. Zeolite as a substitute in concrete has been previously researched by Agita Marsaulina Simanjuntak (2020) in a journal entitled "*Pengaruh Penambahan Zeolite Sebagai Substitusi Semen Terhadap Sifat Mekanik Beton*" In this research it was concluded that the highest compressive strength was obtained at a zeolite substitution level of 10% of the cement weight used, and the compressive strength obtained was 34.34 MPa.

D. Digital Image Correlation

Digital Image Correlation (DIC) is a method used to measure material displacement by tracking changes in a random speckle pattern on the specimen's surface. This technique works by identifying a region in the deformed image that closely matches a segment of the reference image (taken without any load) through a normalized cross-correlation score [7]. Based on GOM, 2018 [8] to identify deforming areas in an image, various approaches are available. Adaptive methods include image correlation and the least squares method. The fundamental assumption is that there is a causal connection between the original state and the deformed state.

$$f = (x, y) \longleftrightarrow g\ (x_t, y_t,)$$

The correlation function provides a rate for the similarity of two signals f and g.

$$c\ (\Delta x, \Delta y) = \frac{\langle f\ (x, y), g\ (x + \Delta x, y + \Delta y)\rangle}{|f\ (x, y)|.\,|g\ (x, y)|}$$

In the equation, the standard scalar product is used, and Δx and Δy represent the displacements in their respective directions. Thus, the similarity between two subsets of pixels (facets and the search area) at different scanned locations and with different displacements is defined. Various subpixel interpolations, such as bilinear interpolation, bicubic interpolation, or spline interpolation, provide the corresponding maximum similarity in the subpixel area. Using the iterative algorithm, the squares of the gray value differences are minimized at various scanned positions.

2. METODHOLOGY

The following is explanation elaborates stages that are conducted in this research:

A. Physical Testing Material

Physical testing of materials is conducted on coarse aggregate, fine aggregate, and zeolite.

1. Analysis of fine aggregates from Lumajang.
    a) Water content,
    b) Gradation,
    c) Unit weight,
    d) Specific gravity,
    e) Organic content,
2. Analysis of coarse aggregates from Pasuruan.
    a) Water content
    b) Gradation,
    c) Unit Weight,
    d) Specific gravity,
    e) Hardness of coarse aggregate.
3. Analysis of zeolite
    a) Specific gravity,
    b) Finess test

B. Mix Design Calculation

Mix design calculation in this research guided by SNI 03-2834-2000.

C. Slump Test

The examination of slump test in this research is guided SNI 1972:2008.

D. Compressive strength procedure

Concrete compressive strength testing, guided by SNI 1974-2011.

E. Flexural test procedure

The concrete flexural strength test carried out was guided by SNI 4431:2011.

F. Procedure for taking pictures

The examination of procedure of taking pictures can generally conducted through the following steps:

1. Placing the test object on the compressive plate.
2. Setting the camera height so that it is parallel to half of the test object so that the camera can take pictures right in the middle of the test object.
3. Make sure the distance between the camera and the test object is not too close so that the camera frame can capture the readings of the dial numbers and the test object
4. Make sure the camera position does not shift during the test, this can be circumvented by using a remote shutter.
5. Taking pictures continuously from before the test object is loaded until the test object experiences the first crack.

G. DIC analysis

The following is how to analyze the image of the test piece obtained during testing with the Zeiss inspect correlate application:

1. Open the Zeiss quality suite, then select Inspect Correlate.
2. Importing the image.
3. Creating surface components.
4. Calibrating the image size of object.
5. Making point inspection.
6. Click Inspect All visible actual elements.
7. Selecting strain for cylinder sample, and Displacement Y to see deflection using beam sample.

3. RESULT AND DISCUSSION

The following results were obtained in this research:

A. Physical testing material result

The physical testing result of coarse aggregate and fine aggregates can be found in **Table 1** and **Table 2**.

Table. 1 Physical testing result of coarse aggregates

Coarse aggregate testing	Result	Unit	Standard	Reference
Water content	1.84	%	1-5%	SNI-1971-2011
Finess modulus	6.98		5.0-8.0	ASTM C 136-01
Oven dry bulk specific gravity	2.737	gr/cm^3	2.5-2.7	SNI 1970-2008
SSD Specific gravity	2.779	gr/cm^3	2.4-2.7	
Apparent specific gravity	2.857	gr/cm^3	2.4-2.8	
Loose unit weight	1.34	gr/cm^3	1.3-1.9	ASTM C-29M-03
Pound unit weight	1.43	gr/cm^3		
Shake unit weight	1.45	gr/cm^3		
Gradation	20 mm		-	SNI03-2847-2000

Table. 2 Physical testing result of fine aggregates

Fine aggregate testing	Result	Unit	Standard	Reference
Water content	3.99	%	5-10%	SNI-1970-2008
Finess modulus	3.33		1.5-3.8	SII-0052
Oven dry bulk specific gravity	2.66	gr/cm^3	2.5-2.7	SNI 1970-2008
SSD Specific gravity	2.69	gr/cm^3	2.4-2.7	
Apparent specific gravity	2.74	gr/cm^3	2.4-2.8	
Loose unit weight	1.59	gr/cm^3	1.3-1.9	ASTM C-29M-03
Pound unit weight	1.69	gr/cm^3		
Shake unit weight	1.70	gr/cm^3		
Gradation	zone 1	-	-	SNI 03-2847-2000

B. Compressive strength and flexural strength result

The compressive strength and flexural strength tests are carried out when the concrete has reached the age of 28 days, this test is carried out simultaneously with taking pictures that will be used for DIC analysis. The result of compressive strength can be found in the **Table 3**, and the flexural strength result can be found in **Table 4**.

Table. 3 Compressive strength result

No.	Date		Age (days)	Variation	***Stress* (N/mm^2)**
	Production	Testing			
1	Apr 2nd, 24	Apr 30th, 24	28	**0%**	29.10
2	Mar 5th, 24	Apr 2nd, 24	28	**10%**	25.02

Table. 4 Flexural strength result of 0% zeolite

No.	Date		Age (days)	Variation	***Flexural beam stress (N/mm2)***
	Production	Testing			
1	Apr 2nd, 24	Apr 30th, 24	28	**0%**	6.88
2	Mar 5th, 24	Apr 2nd, 24	28	**10%**	4.13

The comparison graph of the compressive strength and flexural strength of concrete at 28 days with variations of 0% and 10% shown in **Figure 1** and **Figure 2**.

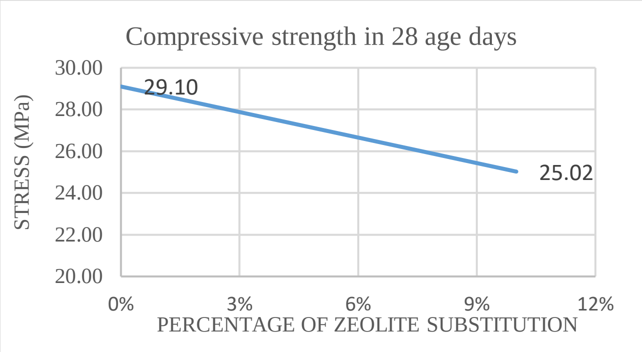

Figure 1 Compressive strength comparison

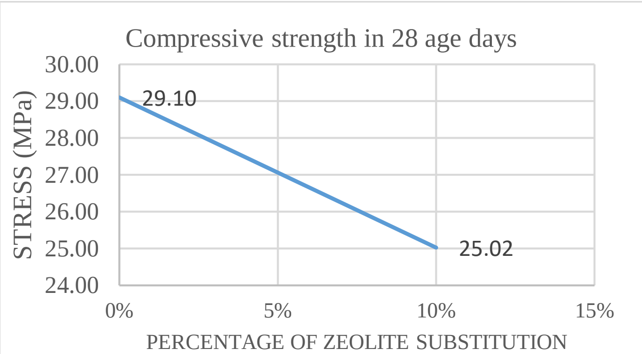

Figure 2 Flexural strength comparison

Based on Figures 1 and 2, it can be seen that there is a decrease in compressive strength in concrete with zeolite substitution by 8% and a decrease in flexural strength by 25%. Therefore, it can be concluded that zeolite cannot be used as a cement substitute in concrete

C. DIC analysis result

The following will discuss the results of DIC strain and deflection analysis using Zeiss inspect correlate 2023 software on normal concrete and concrete with 10% zeolite substitution.

1. Normal concrete

The largest strain value in each of the NS1 to NS5 specimens was obtained 0.0038; 0.0030; 0.0029; 0.0036; 0.0033 and the average obtained in the five specimens was 0.0033. The result of each specimen can be found in **Figure 3**.

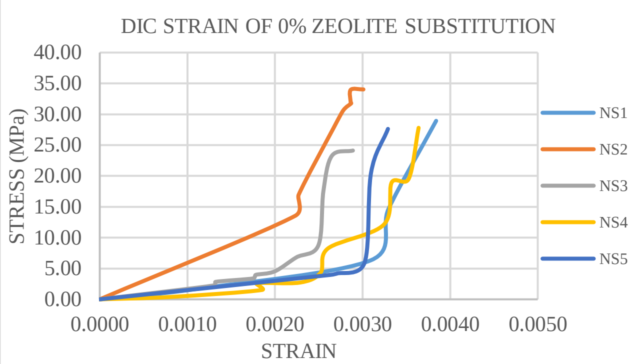

Figure 3 DIC Strain of 0% zeolite substitution

The largest deflection value in each test specimen NB1 to NB3 was obtained 1.976; 0.786; 0.998; and the average obtained in the three test specimens is 1.253. The result of each specimen can be found in **Figure 4**.

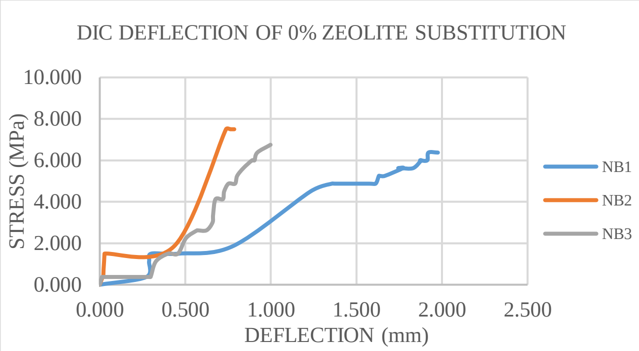

Figure 4 DIC Deflection of 0% zeolite substitution

2. 10% zeolite substitution concrete

The largest strain value in each test specimen ZS1 to ZS5 was obtained 0.0045; 0.0041; 0.0043; 0.0046; 0.0043 and the average obtained in the five test specimens was 0.0044. The result of each specimen can be found in **Figure 5**.

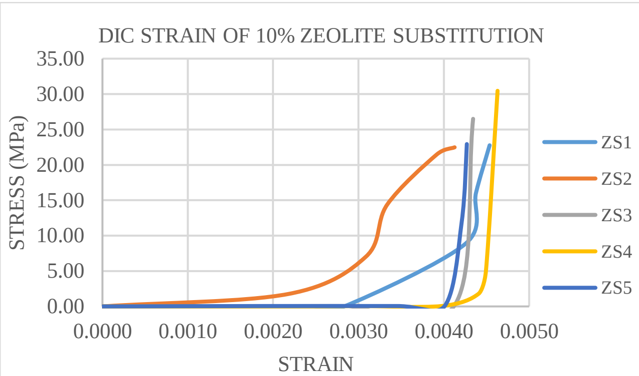

Figure 5 DIC strain of 10% zeolite substitution

The largest deflection value in each test specimen ZB1 to ZB3 was obtained 1.426; 1.633; 2.010; and the average obtained in the three test specimens was 1.690. The result of each specimen can be found in **Figure 6**.

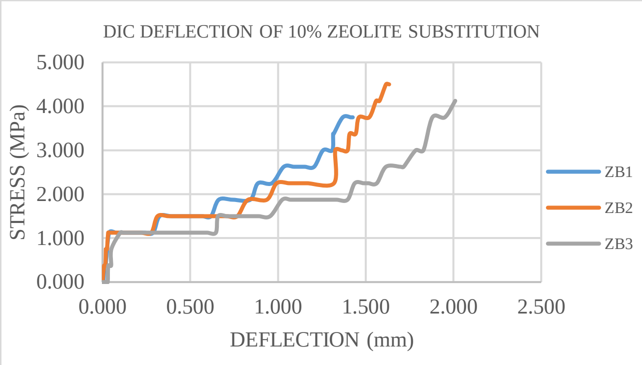

Figure 6 DIC deflection of 10% zeolite substitution

D. Comparison of DIC analysis and instruments measurement

The following is a discussion of strains using the DIC method and instruments on normal concrete and zeolite subsitituted concrete.

1. DIC strain vs instrument strain

The average strain measurement for concrete without zeolite substitution using the DIC method is 0.00333, while the strain measurement from the extensometer is 0.00331 and the strain in concrete with zeolite substitution is 0.0044 from DIC analysis, while the strain that obtained from extensometer is 0.0042. The strain measurement from the extensometer have 0.31% differences compares to measurement from DIC in concrete with 0% substitution, while in concrete with 10% zeolite substitution have differences 1.56%. Result of DIC strain and instrument strain shown in **Table 5** below.

Table. 5 DIC strain Vs Instrument strain result

CODE	**0% Zeolite Substitution**	
	DIC	Extensometer
NS1	0.0038	0.0038
NS2	0.0030	0.0039
NS3	0.0029	0.0029
NS4	0.0036	0.0028
NS5	0.0033	0.0031
Average	0.00333	0.00331
Differences	0.31%	
CODE	**10% Zeolite Substitution**	
	DIC	Extensometer
ZS1	0.0045	0.0042
ZS2	0.0041	0.0044
ZS3	0.0043	0.0042
ZS4	0.0046	0.0045
ZS5	0.0043	0.0040
Average	0.0044	0.0042
Differences	1.56%	

The strain correlation values from the DIC method and the instruments for normal concrete and zeolite substituted concrete from SPSS are 0.975 and 0.737, respectively these values indicate a strong and direct correlation.

2. DIC deflection vs instruments

The average deflection measurement on concrete without zeolite substitution using the DIC method is 1.253, while the deflection measurement from the dial yields a value of 0.956. The deflection measurement from the dial is smaller compared to the DIC measurement, with an average difference of 13%. For concrete with zeolite substitution, the average deflection measurement using the DIC method is 1.690, whereas the deflection measurement using the dial gives a value of 1.478. Result of DIC deflection and instrument deflection shown in **Table 6** below.

Table. 6 DIC deflection Vs Instrument deflection result

CODE	**0% Zeolite Substitution**	
	DIC	Dial
NB1	1.976	1.474
NB2	0.786	0.756
NB3	0.998	0.638
Average	1.253	0.956
Differences	13.46%	
CODE	**10% Zeolite Substitution**	
	DIC	Dial
ZB1	1.426	1.223
ZB2	1.633	1.334
ZB3	2.010	1.877
Average	1.690	1.478
Differences	6.69%	

The deflection correlation values from the DIC method and the dial for normal concrete and zeolite substituted concrete from SPSS are 0.999 and 0.978 respectively, these values indicate a strong and direct correlation.

E. Cost estimation

The unit price used to calculate the cost budget plan in this study was obtained from a market survey. Estimation to conduct this research, shown in **Table 7**.

Table. 7 Cost estimation

Material	Volume	Unit	Unit price		Total	
Fine aggregate	75.89	kg	Rp	375.00	Rp	28,460.53
Coarse aggregate	74.30	kg	Rp	500.00	Rp	37,151.67
Cement	35.96	kg	Rp	1,140.00	Rp	40,996.48
Water	15.15	m3	Rp	5.20	Rp	78.48
Zeolite	1.89	kg	Rp	750.00	Rp	1,419.55
Paint	1	kg	Rp	38,000.00	Rp	38,000.00
Spray paint	2	pc	Rp	34,000.00	Rp	68,000.00
Lighting	2	days	Rp	120,000.00	Rp	240,000.00
Tripod	2	days	Rp	20,000.00	Rp	40,000.00
Total Price					Rp	494,107.00

4. CONCLUSION

Based on the research conducted, the following are the conclusions drawn from this study:

1. Concrete with zeolite substitution has lower compressive strength and flexural strength compared to concrete without zeolite substitution. In this study, the compressive strength of concrete without zeolite substitution was found to be 29.10 MPa at 28 days, while the compressive strength of concrete with zeolite substitution was 25.02 MPa. The flexural strength of concrete without zeolite substitution at 28 days was 6.88 MPa, while for concrete with zeolite substitution, it was 4.13 MPa. It’s mean that zeolite as cement substitution can’t increase the compressive strength and flexural strength of concrete.
2. The strain measurement results using DIC analysis on normal concrete (0% zeolite substitution) have an average of 0.0033, while concrete with 10% zeolite substitution has an average of 0.0044. This measurement shows a difference of 14%. The deflection measurement results using DIC analysis on normal concrete (0% zeolite substitution) have an average of 1.253, while concrete with 10% zeolite substitution has an average of 1.690. This measurement shows a difference of 15%. Concrete with zeolite substitution has greater deflection and strain than normal concrete. Based on this, it can be concluded that zeolite as a cement substitute cannot reduce strain and deflection in concrete.
3. The strain measurement results on normal concrete using DIC method have an average of 0.00333, while measurements using an extensometer have an average strain of 0.00331, indicating a difference of 0.31 % between these two methods. Meanwhile, strain measurements on concrete with zeolite substitution using DIC method have an average of 0.0044, and measurements using the instrument have an average strain of 0.0042, showing a difference of 1.56% between these two methods. The deflection measurement results on normal concrete using DIC method have an average of 1.253, while measurements using a dial have an average of 0.956, indicating a difference of 13.46%. On the other hand, deflection measurements on concrete with zeolite substitution using DIC method have an average of 1.690, and measurements using a dial have an average of 1.478, showing a difference of 6.69%. Therefore, it can be concluded that the DIC method can be used to measure maximum strain and deflection in concrete; however, the strain-stress graph obtained from the DIC method cannot be used to determine $\beta 1$.
4. The total cost for conducting strain and deflection measurements using the DIC method is Rp. 494,107.00 (four hundred ninety-four thousand one hundred seven Indonesian Rupiah).

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